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BBC

RESEARCH DEPARTMENT REPORT

Field-store standards conversion: the testing of ultrasonic delay-lines

No. 1969/12

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

FIELD STORE STANDARDS CONVERSION : THE TESTING OF ULTRASONIC DELAY-LINES

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for Head of Research Department

(EL-24)

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SUMMARY

The careful design and comprehensive testing of ultrasonic delay lines for television applications is essential if a satisfactory performance is to be obtained. Both design and testing require close liaison between customer and supplier and the ways in which performance is specified and measured are intimately related. An earlier report, EL-13, described the procedure for specifying delay-line performance and this report deals with methods of testing completed lines.

The report describes the conditions of test, characteristics to be measured, special test signals and measuring apparatus, test procedures and the presentation of results.

Several years of experience in the testing of delay lines have contributed to the evolution of methods which give reliable and accurate results and ensure that the specification is satisfied in all respects that influence the quality of television pictures from delayed signals.

1. INTRODUCTION

Ultrasonic delay-lines, which have been in use for many years to provide the wide bandwidth delays required for data processing and radar systems, are now finding applications in television. Apparatus for vertical aperture correction,[1] interpolation between adjacent television lines,[2] and field-store standards conversion[3] all employ ultrasonic delay lines.

In television applications, the performance of the delay line must meet an exacting specification; for example, the delay time must be accurate, the bandwidth must exceed that of the television system and spurious effects must be imperceptible on the final picture. It is therefore essential to specify precisely the required performance when ordering from a manufacturer and to test the line very thoroughly when it is received.

The specification of ultrasonic delay lines has been fully described elsewhere[4] and the object of this report is to describe the procedures used when testing ultrasonic delay lines which have been manufactured to a prepared specification. The importance of such acceptance testing cannot be over-emphasised. The basic requirements may be listed.

Testing methods must:

(a) Cover all items included in the specification. To ensure that no tests are omitted at the time of testing it has been found valuable to use one or more printed forms.

(b) Be compatible with the methods of test used by the manufacturer. This is particularly important in that it avoids ambiguities and misunderstandings. Preliminary discussions with a manufacturer on the standardization of testing methods are particularly valuable in this respect.

(c) Be sufficiently accurate and defensible in case of query or dispute.

2. TEST CONDITIONS

Ultrasonic quartz delay lines are tested under conditions often different in many respects from the conditions under which the line will finally be operated. For example, the specification may require the transducers simply to be tuned and damped for test purposes whereas, in the practical application, a complex circuit may be used. This difference is taken into account when the specification is first written and in the design of the equipment in which the delay-line will operate. In certain respects, however, it is important that the testing and operating conditions are the same. For example, the operating temperature for test purposes must be the same as the temperature in normal operation because of the dependence upon temperature of such parameters as delay, insertion loss, response/frequency characteristic and spurious signals.

3. TEST SIGNALS

A 'burst' or r.f. pulse, the envelope of which is 'sine-squared' or 'Gaussian' in shape, has proved to be the most versatile signal for delay-line testing. In practice, the pulse has a variable repetition frequency (p.r.f.) and is limited in bandwidth so that its frequency spectrum extends ± 1 MHz on either side of the carrier frequency. This choice of bandwidth represents a compromise between conflicting requirements; a narrow pulse (and hence a wide bandwidth) is required for the accurate measurement of time-delay, whilst a narrow frequency-bandwidth (and hence a wide pulse) is required for the accurate measurement of frequency-dependent parameters.

In addition to the above test signal, other forms of signal are used to a lesser extent. These comprise c.w., swept c.w. and vision signals.

4. TEST APPARATUS

Fig. 1 shows the basic arrangement used in the testing of ultrasonic quartz delays. The input test signal is derived by amplitude-modulating an r.f. carrier with the bandwidth-limited pulse. The r.f. carrier-input to the modulator is obtained from an oscillator whose frequency can be varied over the required band.

It will be seen that the test signal follows two paths, one through the delay under test and the other through a side-chain formed from a calibrated attenuator. The two resultant signals, one of which is delayed and the other undelayed, are combined in a hybrid combining-unit for simultaneous display on an r.f. oscilloscope. Alternative methods of combining are sometimes used and these will be described later. The p.r.f. is adjustable and monitored by a counter.

The modulator can also be switched to a c.w. position to supply a constant-amplitude carrier. In this case the counter is used to monitor the carrier frequency and the r.f. oscilloscope is then used to display c.w. signals only. To preserve accuracy, the calibration of the counter is periodically checked against an external frequency-standard.

In the construction and use of the test equipment, great care is taken to obtain good screening between the input and output networks to avoid direct break-through and consequent inaccuracy of measurement. It is also necessary to achieve a high signal-to-noise ratio at the output, to permit the accurate measurement of low-level signals.

5. TEST PROCEDURE

When carrying out tests on a delay line and particularly when first received from a manufacturer, it is important that no aspects of the specification are overlooked. For this reason the use of printed forms has been introduced. The various items of the specification are printed in a convenient order on the form and any omissions are obvious to the engineer making the tests.

5.1. Measurements at Room Temperature

The delay line is given a general visual examination as soon as it is received.

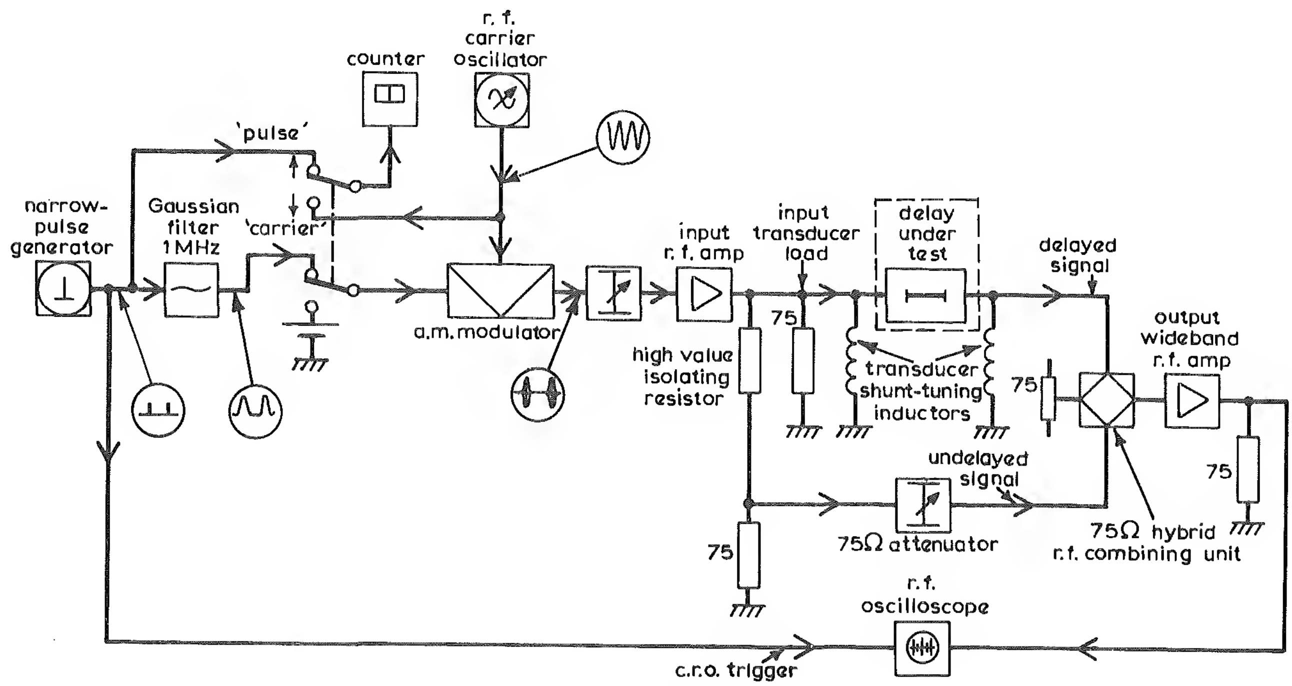


Fig. 1 - Quartz delay basic test equipment

The transducer capacitances are measured, both for record and design purposes and also as a partial check that the delay line has not suffered damage in transit. Other measurements are also made at room temperature, notably insertion-loss and delay in order to obtain figures upon which to base the effects of temperature.

5.2. Operating Temperature

Most ultrasonic delay lines require to operate in a temperature-controlled environment and this is achieved by placing the line in a temperature-controlled chamber or oven. An oven is also required for test purposes. It must be designed for ease of access to the interior, whilst preserving reasonable thermal insulation, and the temperature must be continuously monitored and adjustable up to about 90°C. A temperature stability of about ± 1°C is satisfactory for most tests. To avoid thermal shock to the delay-line and to allow time for the temperature to stabilize before measurement, it is important to allow the line to warm up slowly, usually overnight.

5.3. Measurements at Operating Temperature

5.3.1. Insertion Loss and Passband

Both these measurements are obtained simultaneously in a single group of operations in which the response/frequency characteristic is determined. Referring to Fig. 1, the attenuator is fed through a high-value isolating resistor from the common point at the input to the delay-line under test. The attenuation due to the isolating resistor is previously measured and added to subsequent attenuator readings. When a measurement is made, the p.r.f. of the pulse generator and the time-base of the oscilloscope are adjusted to obtain a display of the delayed and undelayed signals, side-by-side on the oscilloscope. The attenuator is adjusted to obtain equality of the delayed and undelayed signals displayed on the oscilloscope and the attenuator reading, plus the attenuation due to the padding resistor, give the insertion loss of the line. Attenuation of the signal also occurs in the hybrid combining-unit but this is common to both the delayed and undelayed signals and therefore need not be accounted for in the measurement. The procedure is repeated at a number of frequencies so as to explore the whole passband and the results are plotted in graphical form.

It is important that minor variations or ripples in the response/frequency characteristic should not escape detection during these measurements. This requirement is covered by determining the frequencies at which particular values of attenuation occur, rather than the values of attenuation occurring at particular frequencies. 1 dB steps are chosen for this purpose and the output signal level is continuously observed whilst the frequency is slowly varied. A graph of the response/frequency characteristic is now plotted and the passband is determined by the location of the half-power or –3 dB points in the characteristic. The insertion loss is normally specified as the value at the centre of the passband but sometimes as the frequency of minimum-loss, or peak of the response-curve. In applications where many delay-lines are to be operated in cascade with a common signal, it is important that the passband shall lie within specified frequencies rather than merely occupy a particular bandwidth. The field-store standards converter[3] is the best known application of this type and the need for a common passband for the successful transmission of a signal through the cascade of delay lines is readily apparent.

When the response/frequency characteristic is measured in the manner just described, the result is affected by the electrical impedance connected across the output transducer terminals; loading at the input transducer does not affect the results, since both signal paths are common and each can therefore be regarded as being fed from a zero-impedance source. In practice, the specification may state that the response/frequency characteristic is to be measured in this way, due allowance having been made by the designer. However, in some cases it is necessary to modify the method of measurement so that the result is unaffected by the loading impedance and only the true or 'acoustic' response is obtained. Again, this must conform to the specification and be allowed for by the designer of the associated input and output amplifiers. The acoustic response is best described as the short-circuit transfer admittance; its measurement has the advantage of ignoring transducer reactances, but, since the practical specification of insertion loss must suppose finite terminal resistances, the transducer capacitances must be small if the overall amplitude/frequency response is to be reasonably constant.

Fig. 2 shows a simplified equivalent circuit of a delay line and its output transducer. Fig. 3(*a*), the outputs of the attenuator and the delay line are connected in parallel and the inductance is adjusted at each test frequency so as to tune-out the capacitance of the transducer.

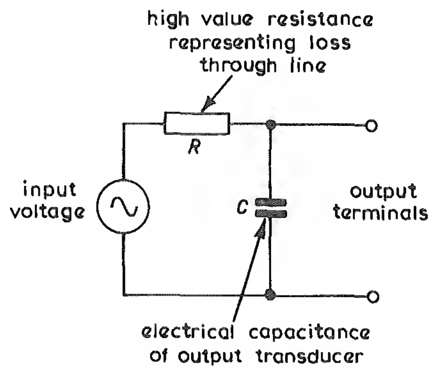


Fig. 2 - Simplified equivalent circuit of delay line

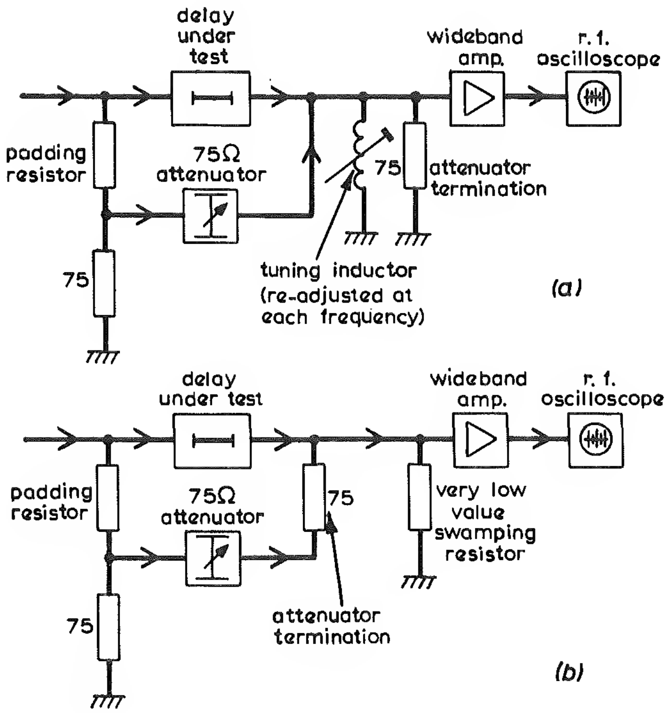


Fig. 3 - Alternative methods for measurement of acoustic response

The attenuator is thereby correctly terminated by the 75Ω resistor and the transducer is damped by the 37·5Ω resistance formed from the parallel combination of the attenuator and its termination. The method is somewhat tedious, however, because of the need for frequent re-tuning and the less accurate method illustrated in Fig. 3(*b*) is more commonly used. In this case a shunt-connected resistor of very low value is used to swamp the unwanted effect of the transducer impedance. Inaccuracy results because the low resistance causes heavy attenuation and a reduction in the signal-to-noise ratio. In practice it is found that the swamping resistor cannot be made sufficiently low to ensure that the measurements are of the acoustic response alone and small errors are therefore incurred.

5.3.2. Spurious Signals

Spurious signals (or secondaries) are observed when signals reach the output transducer by other than the prescribed path, arriving either earlier or later than the main signal. The causes of spurious signals are often very complex and a detailed description is outside the scope of this report. For the purposes of test, however, they may be classified as shown in Table 1 below.

TABLE 1

Description	Abbreviation	Delay Value
Direct Breakthrough	DBT	Zero Delay
Third-Time-Round	TTR	Three times delay of main signal
Largest-Before-Main	LBM	In advance of main signal
Largest-After-Main	LAM	Behind main signal

'Direct breakthrough' occurs because of coupling between the input and output transducer circuits. 'Third-time-round' secondaries occur when the signal is reflected from the output transducer back to the input transducer, where it is reflected again, finally to appear at the output. Other spurious signals, with no obvious mechanism to explain their appearance, are usually clustered in time around the main signal. Some delay lines are found to exhibit a large number of low-level spurious signals; the amplitudes and timings of these are particularly difficult to measure although their cumulative effect can, in some cases, be considerable.

The identification (i.e. timing) of spurious signals is normally accomplished by systematic variation of the pulse repetition frequency and observation of the input and output signals on an oscilloscope. This process is not of special importance, however, except in rare cases or as a means of describing such signals to a manufacturer when a line is being returned as unsatisfactory.

The level of a spurious signal is expressed as a ratio, relative to the level of the main output signal at the same frequency. The measurement of such levels is fairly simple in principle and is carried out by increasing the gain of the oscilloscope to give a convenient deflection when observing the particular spurious signal to be measured. The input signal from the modulator is now attenuated to obtain the same deflection from the main signal and the attenuator reading thus obtained gives the dB ratio of the main signal level to the spurious signal level. It is to be noted that the measurement of very low-level signals depends upon the provision of an adequately high signal-to-noise ratio. It is also necessary to use an oscilloscope whose gain to low-level signals is not impaired by the presence of the very large main signal, the equivalent height of which may correspond to many diameters of the oscilloscope faceplate.

Normally, the levels of spurious signals are found to vary over the frequency band and the values of the stronger signals are plotted on the same graph as the response/frequency characteristic. Most delay lines are so designed that the levels of spurious signals are lowest in the central parts of the passband, rising in level at the extreme edges. In some specifications the tolerable level of spurious signals may have different values in different parts of the passband.

5.3.3. Delay

The specification normally states the required delay at a particular operating temperature and at the band-centre frequency.

Using the equipment shown in Fig. 1, the p.r.f. of the pulse generator is adjusted to give a time-interval between pulses having the same nominal

value as the time-delay to be measured; thus the delayed r.f. output pulse will be displayed on the oscilloscope at approximately the same time as the next, undelayed pulse. The p.r.f. is now carefully adjusted, in conjunction with minor adjustments of the carrier frequency, until the delayed and undelayed pulses are brought into coincidence and are seen to cancel. Some slight adjustment of the relative pulse amplitudes may also help, but perfect cancellation is not necessary to obtain an accurate measurement. The counter is connected to the output of the pulse-generator for this measurement and hence gives a direct indication of the delay. By comparison with the value measured earlier at room temperature, the temperature coefficient of delay can also be determined.

The above method of delay measurement is satisfactory for most practical delays and is capable of an accuracy limited only by the accuracy of the counter and the care of the operator. In a practical test, however, where it is required to measure the delay at a particular operating temperature, the accurate measurement of the temperature of the delay-line itself represents the limiting factor. This is especially noticeable with larger delay-lines which require a long period for warm-up and which may be difficult to maintain at a uniform temperature in the test oven. For fused-quartz delay-lines, the temperature coefficient of delay is approximately 70 parts per million per degree centigrade and a temperature stability of about $\pm 1^{\circ}$C can be achieved without difficulty. This is sufficiently good in most cases.

For very short delays of a few microseconds the method just described is inconvenient and insufficiently accurate. A special, narrower pulse could probably be used but, in practice, an unmodulated (c.w.) input is selected (see Fig. 1) and the counter is used to measure the carrier frequency itself. Measurement of delay is accomplished by carefully adjusting the carrier frequency and the attenuator to give a null on the output oscilloscope display. Thus the delay-path will be longer than the direct path by an odd, integral multiple of carrier half-periods, assuming no reversals of polarity to occur in the equipment. The frequency corresponding to the null is now measured using the counter and its value is recorded. This procedure is repeated for a small number of adjacent carrier frequencies close to the centre of the passband, each frequency being carefully recorded. The actual delay is now calculated as follows:

i) An approximate value for the delay is obtained by computation, taking the reciprocal of the difference between two adjacent null-frequencies.

ii) The precise delay is that value nearest to the value obtained in (i) which can be obtained by multiplying the carrier half-period by an odd whole number. Apart from any slight effects due to dispersion in the delay-line, each frequency should give the same value of delay, within normal experimental limits, and a final result is obtained by averaging.

To preserve accuracy it is also necessary to measure and allow for the delay in the circuits external to the delay-line. This is accomplished using similar techniques to those just described, a check being made at the same time for any unknown reversals in polarity within the test equipment.

5.3.4. Other Measurements

'Swept' response/frequency characteristics are also measured, of both the delayed and undelayed paths, and a photograph of the display is preserved for record purposes. This provides a quick routine check and is also a useful indicator of ripples in the response/frequency characteristic of the delay-line.

In addition, a vision signal is obtained from either a television test card or a line-frequency sawtooth waveform and is passed through the delay line, after which it is demodulated and examined on a television picture monitor. A subjective appraisal of performance is thus made which is particularly valuable in observing the effects of spurious signals in cases of marginal acceptability.

6. EXAMINATION OF RESULTS

As the test proceeds, the printed form and graph are completed and a comparison between the specification and test report is made. In general, the specification must be adhered to, but occasionally it may be decided that the specification is over-stringent and a delay-line may be accepted when outside the specification by a small amount. Figs. 4 and 5 illustrate a completed table and graph in a typical case. With reference to Fig. 4, it will be seen that a direct comparison can be made between the measured and specified figures and that the line in question fails on account of the high levels of spurious signals. Fig. 5 illustrates the response/frequency characteristic for the same delay line as well as the spurious signals. It will be seen that the measured band centre frequency differs by about 1·5 MHz relative to the specified value but this is unimportant in this case because of the abnormally wide passband. It will also be seen that the main cause of failure is the 'third-time-round' secondary signal which is well outside the specification at all frequencies lower than 27 MHz. The specified maximum secondary signal levels in the example shown are relaxed in regions near the edges of the band and this can be seen graphically in Fig. 5.

7. CONCLUSIONS

A satisfactory system has been established for the testing of ultrasonic delay lines for use in television and the methods used have been agreed by the principal manufacturers. Using these methods a delay line can be tested completely within 24 hours.

BRITISH BROADCASTING CORPORATION – RESEARCH DEPARTMENT

ULTRASONIC DELAY LINE TEST REPORT

MANUFACTURER:- . . ———	NOMINAL DELAY:- .66·3 μs at . 40 . . °C.
TYPE No.:- . . . . ———	MATERIAL:- . . ——— . . . . .
SERIAL No.:- . . . . ———	

	MEASURED	BBC SPECIFICATION
TRANSDUCER IMPEDANCE Input (1) Output (2)	66·1 pf 68·2 pf	≤ 300 pf
TRANSDUCER LOADING Input (1) Output (2)	75 Ω	} 75 Ω
DELAY AT OPERATING TEMPERATURE AT OTHER TEMPERATURE	66·295 μs at 40 °C. 66·37 μs at 23 °C.	66·3 μs at 40 °C.
* INSERTION LOSS	0** dB at 24 MHz 55 dB at 30 MHz +2** dB at 36 MHz	-3** dB at 24 MHz <60 dB at 30 MHz -3** dB at 36 MHz
* MAX. SLOPE OF INSERTION LOSS	1 dB/MHz at 25 MHz) 0·8 dB/MHz at 37 MHz)	± 3/4 dB/MHz from 24 MHz to 36 MHz
* MAX. LEVEL OF SECONDARIES RELATIVE TO MAIN SIGNAL Direct Breakthrough Third-Time-Round Largest Before Main Largest After Main Other	-45 dB at 33 MHz) -37 dB at 24 MHz) -46 dB at 26 MHz) dB at MHz) dB at MHz)	-46 dB from 25 MHz to 33 MHz rising to -40 dB at 24 MHz and 36 MHz
TEMPERATURE COEFFICIENT OF DELAY	67 parts/million/°C.	<100 parts/million/°C.
TEMPERATURE COEFFICIENT OF INSERTION LOSS	0·057 dB/°C	<0·2 dB/°C

* See Transmission/Frequency Characteristic

** Relative to level at 30 MHz

Remarks:- Rejected because of excessive spurious signal levels

Date Received .3. January. 1968

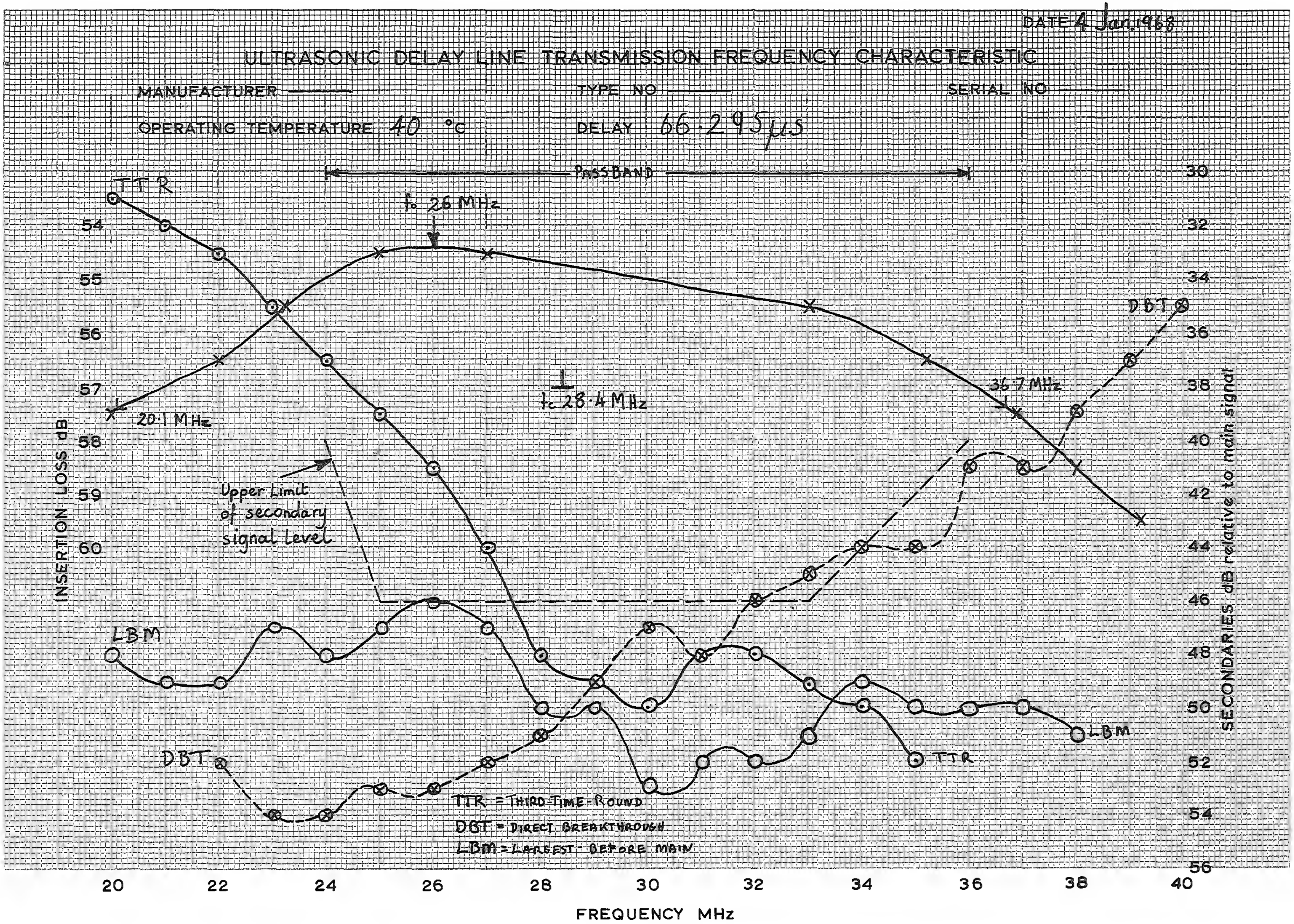
Tested 4 January .1968

Installed . . ——— . . . .

Returned . . ——— . . . .

Fig. 4 - Typical completed test form

RA 18377 (issue 2)



DATE 4 Jan. 1968
ULTRASONIC DELAY LINE TRANSMISSION FREQUENCY CHARACTERISTIC
MANUFACTURER
TYPE NO
SERIAL NO
OPERATING TEMPERATURE 40 °C
DELAY 66·295 μs
PASSBAND
TTR
f₀ 26 MHz
DBT
36·7 MHz
20·1 MHz
fc 28·4 MHz
Upper Limit of secondary signal Level
LBM
TTR = THIRD-TIME-ROUND
DBT = DIRECT BREAKTHROUGH
LBM = LARGEST BEFORE MAIN
INSERTION LOSS dB
SECONDARIES dB relative to main signal
FREQUENCY MHz

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